Look It Up:
Real-Life Database Indexing

Christophe Pettus
PostgreSQL Experts
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Christophe Pettus

CEO, PGX Inc.

christophe.pettus@pgexperts.com

twitter @xof

Indexes!

- We don’t need indexes.
- By definition!
- An index never, ever changes the actual result that comes back from a query.
- A 100% SQL Standard-compliant database can have no index functionality at all.
- So, why bother?

O(N)

~~O(N)~~

O(N)

- Without indexes, all queries are sequential scans (at best).
- This is horrible, terrible, bad, no good.
- The point of an index is to turn O(N) into O(*something better than* N).
    - Ideally O(*log*N) or O(1)
- But…

Just a reminder.

- Indexes are essential for database performance, but…
- … they do not result in speed improvements in all cases.
- It’s important to match indexes to the particular queries, datatypes, and workloads they are going to support.
- That being said…
- … let’s look at PostgreSQL’s amazing indexes!

The Toolbox.

- B-Tree.
- Hash.
- GiST.
- GIN.
- SP-GiST.
- BRIN.
- Bloom.

Wow.

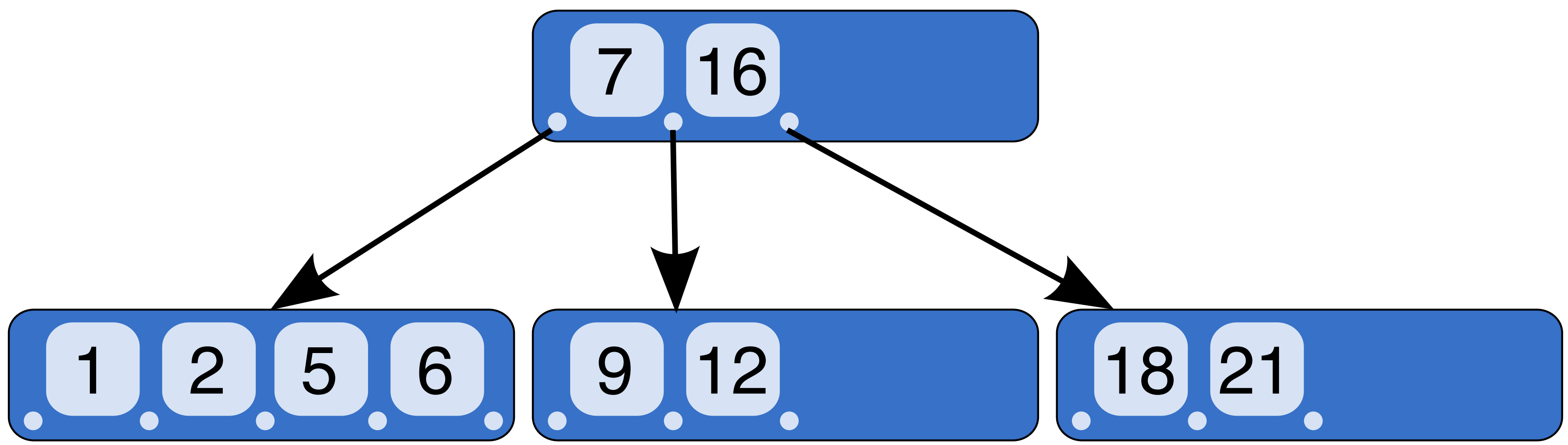
- PostgreSQL has a wide and amazing range of index types.
- Each has a range of queries and datatypes that they work well for.
- But how do you know which one to use?
- Someone should give a talk on that.


B-Tree.

B-Tree Indexes.

- The most powerful algorithm in computer science whose name is a mystery.
  - Balanced? Broad? Boeing? Bushy? The one that came after A-Tree indexes?
- Old enough to be your parent: First paper published in 1972.
- The “default” index type in PostgreSQL (and pretty much every other database, everywhere).

It’s that graphic again.



So many good things.

- B-Trees tend to be very shallow compared to other tree structures.
  - Shallow structures mean fewer disk page accesses.
- Provide O(*log*N) access to leaf notes.
- Easy to walk in ordered directions, so can help with ORDER BY, merge joins…

B-Trees, PostgreSQL Style.

- PostgreSQL B-Trees have a variable number of keys per node…
  - … since PostgreSQL has a wide range of indexable types.
- Entire key value is copied into the index.
- Larger values means fewer keys per node, so deeper indexes.

Recent Improvements

- Significant improvements to B-Tree structure.
- Smaller indexes, especially with many duplicate keys.
- Requires that the index be reconstructed if it exists already.
    - A quick REINDEX CONCURRENTLY will handle it.

Perfect! We're Done.

- Not so fast.
- "Entire key value is copied into the index."
  - Not good (or not available) for long data types.
- Requires a totally-ordered type (one that supports =, <, > for all values).
  - Many, many datatypes are not totally-ordered.

Hash.

Hash Indexes.

- Converts the input value to a 32-bit hash code.
- Hash table points to buckets of row pointers.
- Works on data of arbitrary length.

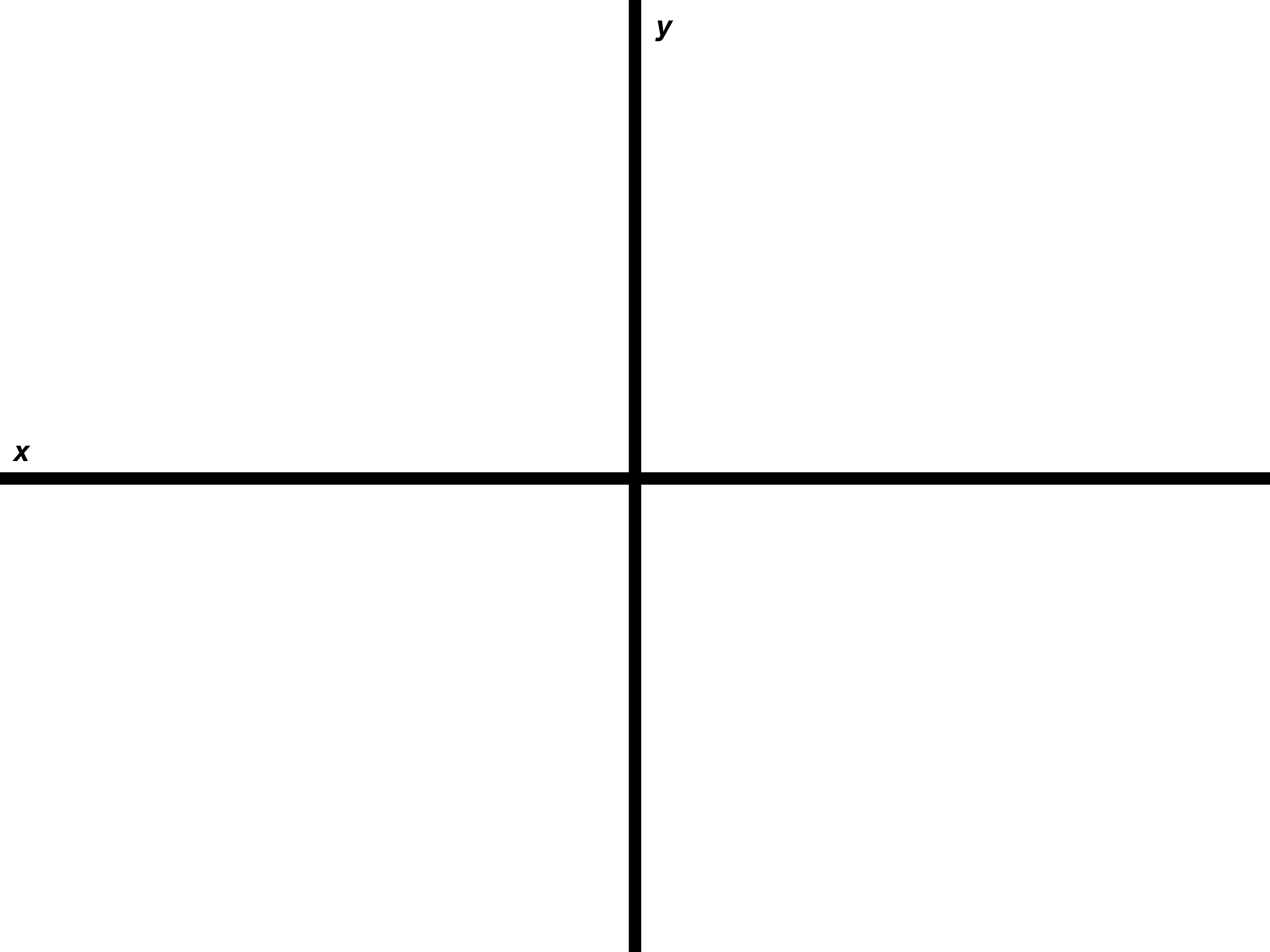
Making a hash of it.

- Only supports one operator: =.
  - But that's a pretty important operator.
- Indexes are smaller than B-Tree, especially for large key values.
  - Access can be faster, too, if there are few collisions.
- Great for long values on which equality is the primary operation.
  - URLs, long hash values (from other algorithms), etc.

GiST.

GiST Indexes.

- GiST is a framework, not a specific index type.
- GiST is a generalized framework to make it easy to write indexes for any data type.
- What a GiST-based index does depends on the particular type being indexed.
- For example: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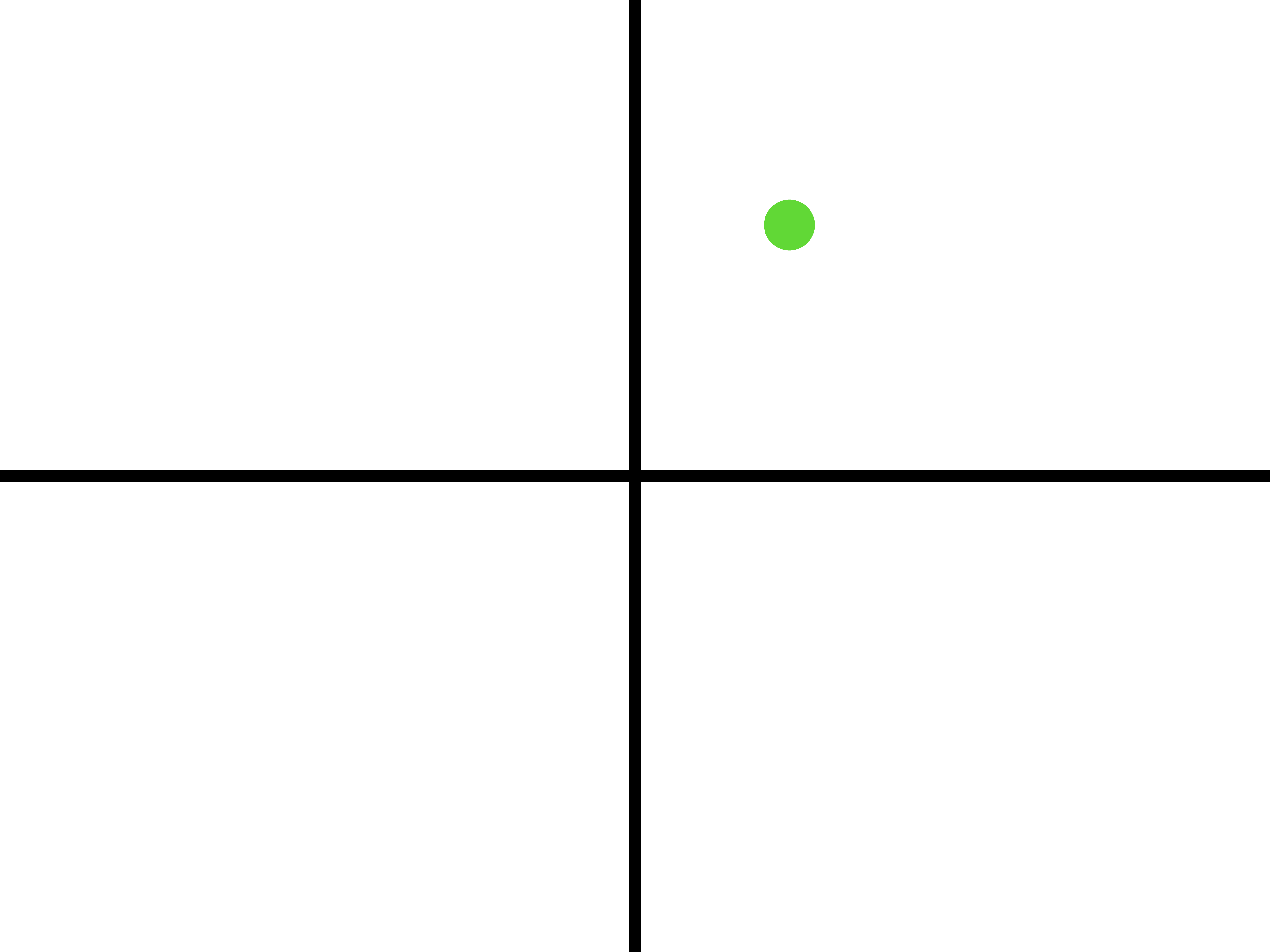
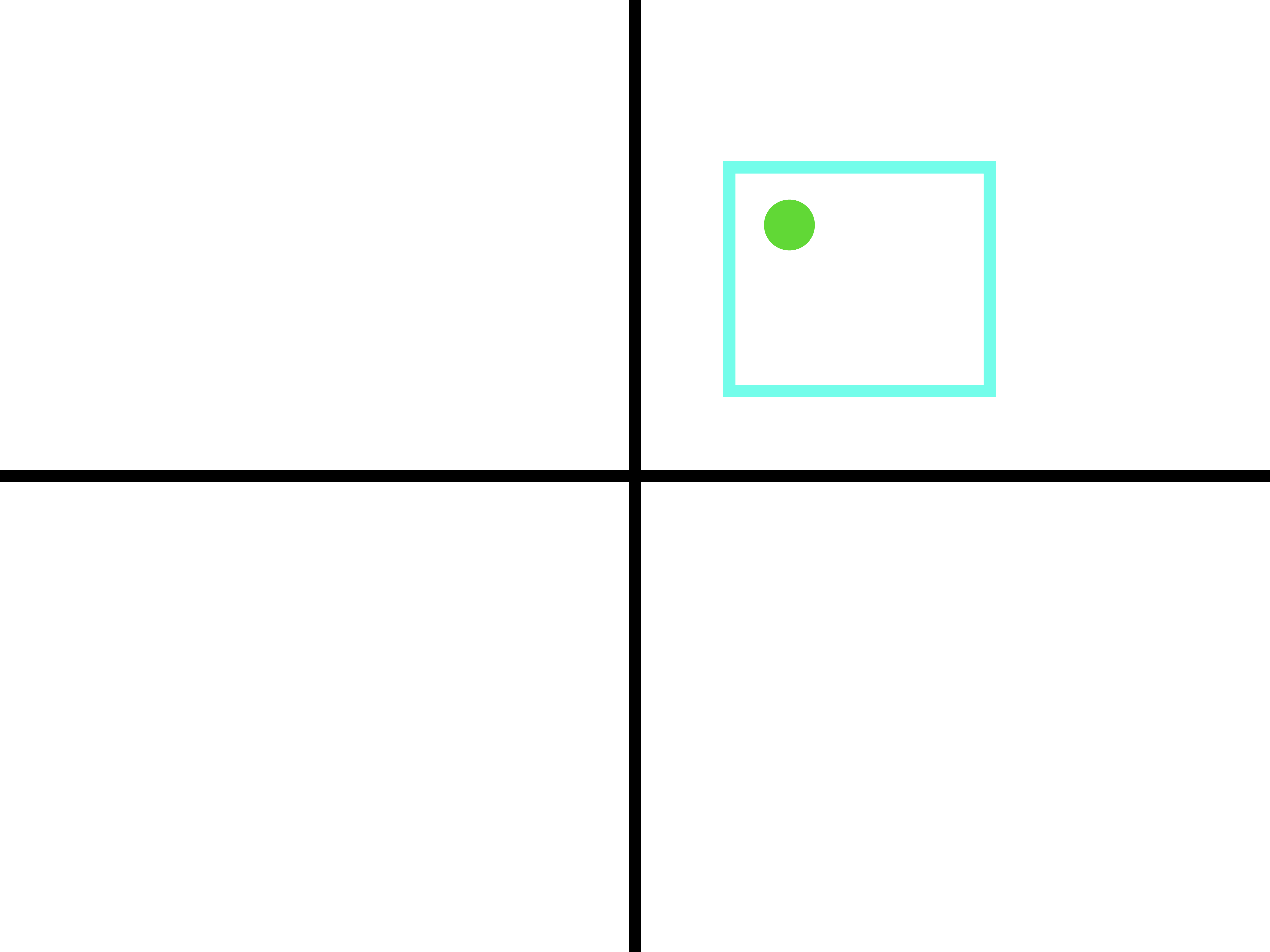
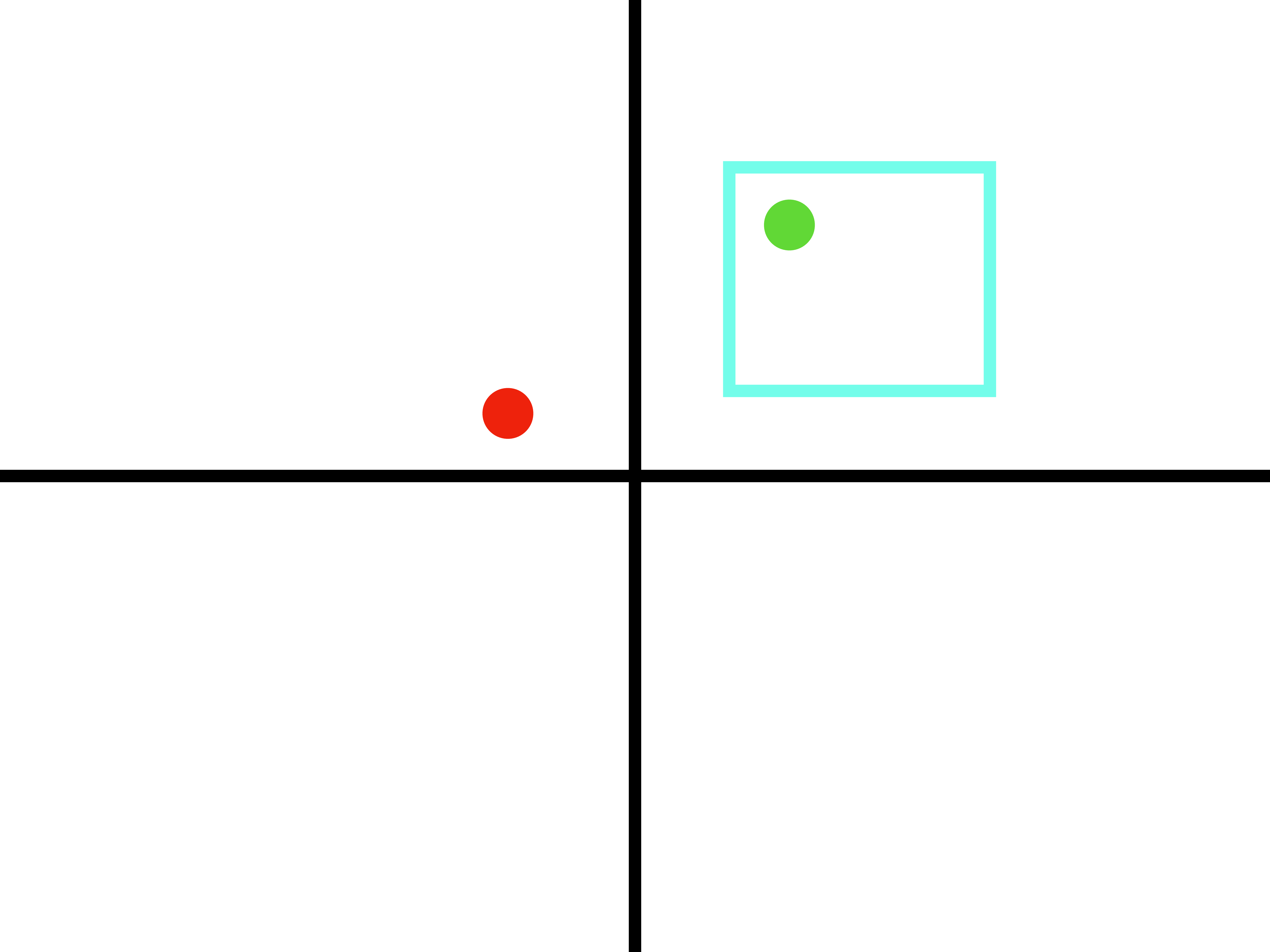
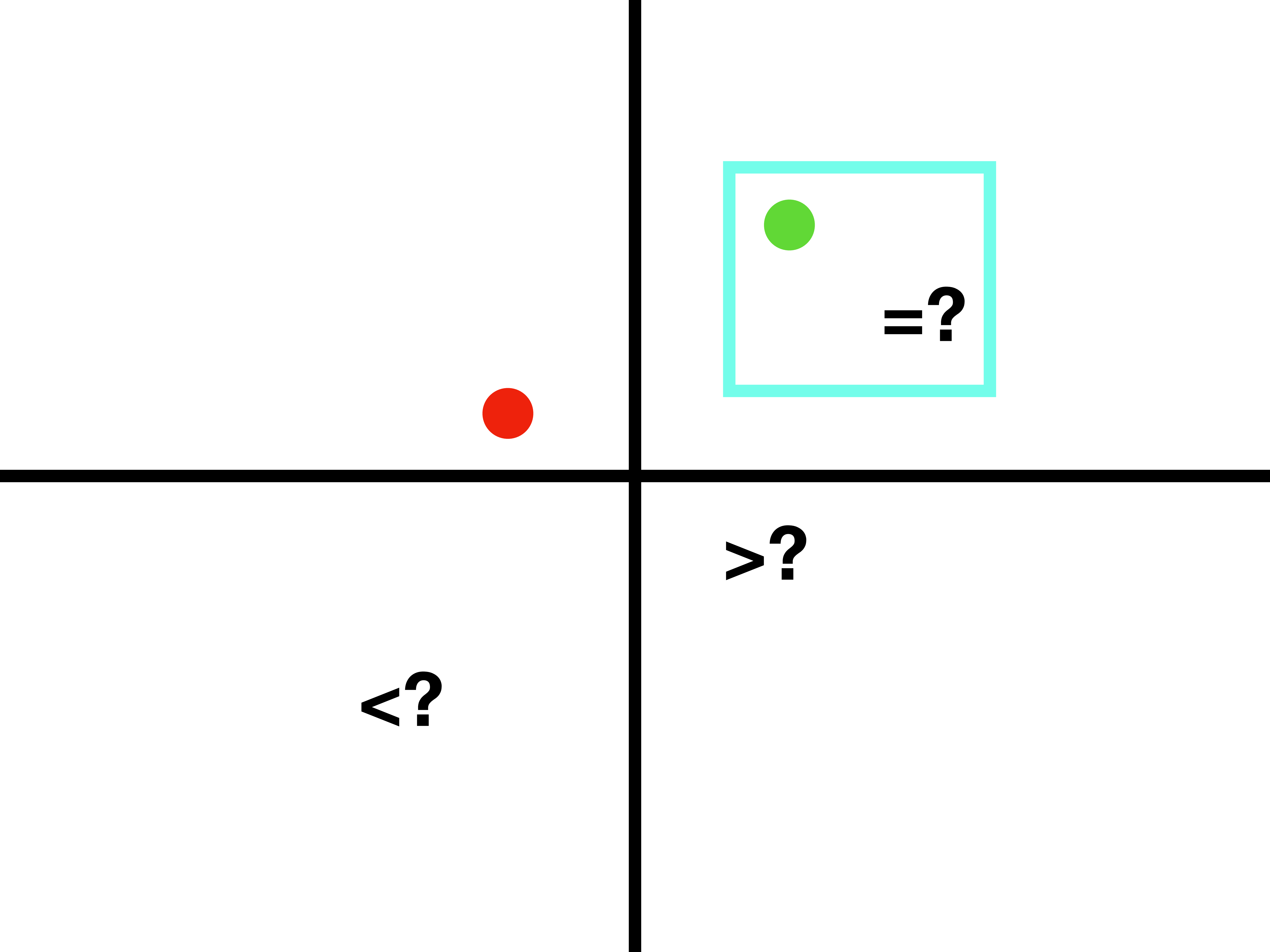
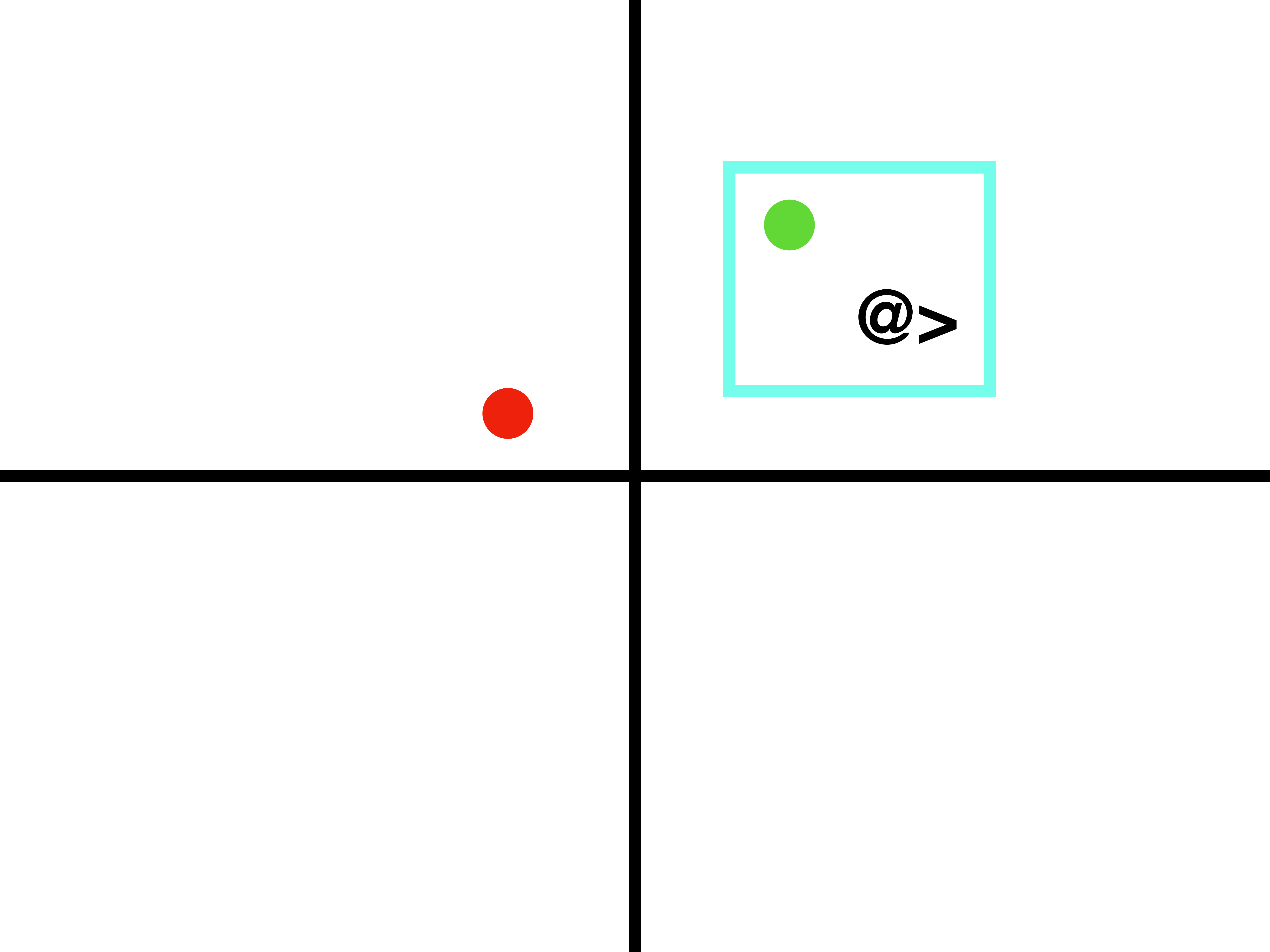










<u>G</u>enerali<u>z</u>ed <u>S</u>earch <u>T</u>ree.

- Can be used for any type where “containment” or “proximity” is a meaningful operation.
  - Standard total ordering can be considered a special case of proximity[citation required].
- Ranges, geometric types, text trigrams, etc., etc…
- Not as efficient as B-Tree for classic scalar types with ordering, or for simple equality comparisons.

GIN.

General Inverted iNdex.

- Both B-Tree and GiST perform poorly where there are lots and lots of identical keys.
- However, full text search (as the most classic case) has exactly that situation.
- A (relatively) small corpus of words with a (relatively) large number of records and positions that contain them.
- Thus, GIN!

A Forest of Trees.

- GIN indexes organize the keys (e.g., normalized words) into a B-Tree.
- The “leaves” of the B-Tree are lists or B-Trees themselves of pointers to rows that hold them.
- Scales very efficiently for a large number of identical keys.
    - Full-text search, indexing array members and JSON keys, etc.

SP-GiST.

Space Partitioning GiST.

- Similar to GiST in concept: A framework for building indexes.

- Has a different range of algorithms for partitioning than "classic" GiST.

- Designed for situations where a classic GiST index would be highly unbalanced.

- More later!

BRIN.

Block-Range INdex.

- B-Tree indexes can be very large.
    - Not uncommon for the indexes in a database to exceed the size of the heap.
- B-Trees assume we know nothing about a correlation between the index key and the location of the row in the table.
- But often, we do know!

`created_at timestamptz default now()`

- Tables that are INSERT-heavy often have monotonically increasing keys (SERIAL primary keys, timestamps)…
- … and if the tables are not UPDATE-heavy, the key will be strongly correlated with the position of the row in the table.
- BRIN takes advantage of that.

BRIN it on.

- Instead of a tree of keys, records ranges of keys and pages that (probably) contain them.
- Much, much smaller than a B-Tree index.
- If the correlation assumption is true, can be much faster to retrieve ranges (like, “get me all orders from last year”) than a B-Tree.
- Not good for heavily-updated tables, small tables, or tables without a monotonically-increasing index key.

Bloom.

Bloom Filters

- Like a hash, only different!
- Most useful for indexing multiple columns at once.
- Very fast for multi-column searches.
  - Multiple attributes, each expressed as its own column.
- A small fraction of the size of multiple B-Tree indexes.
  - Potentially faster for a large number of attributes.

Pragmatic Concerns

Do you need an index at all?

- Indexes are expensive.
  - Slow down updates, increase disk footprint size, slow down backups / restores.
- As a very rough rule of thumb, an index will only help if less than 15-20% of the table will be returned in a query.
- This is the usual reason that the planner isn't using a query.

Good Statistics.

- Good planner statistics are essential for proper index usage.
- Make sure tables are getting ANALYZEd and VACUUMed.
- Consider increasing the statistics target for specific columns that have:
  - A lot of distinct values.
  - More distribution than 100 buckets can capture (UUIDs, hex hash values, tail-entropy text strings).
- Don’t just slam up statistics across the whole database!

Bad Statistics.

- 100,000,000 rows, 100 buckets, field is not UNIQUE, 25,000 distinct values.

- `SELECT * FROM t WHERE sensor_id=‘38aa9f2c-3e5d-4dfe-9ed7-e136b567e4e2’`

- Planner thinks 1m rows will come back, and may decide an index isn’t useful here.

- Setting statistics higher will likely generate much better plans.

Indexes and MVCC.

- Indexes store every version of a tuple until VACUUM cleans up dead ones.
  - The HOT optimization helps, but does not completely eliminate this.
- This means that (in the default case) index scans have to go out to the heap to determine if a tuple is visible to the current transaction.
- This can significantly slow down index scans.

Index-Only Scans.

- If we know that every tuple on a page is visible to the current transaction, we can skip going to the heap.
- PostgreSQL uses the visibility map to determine this.
- If the planner thinks “enough” pages are completely visible, it will plan an Index-Only Scan.
- Nothing you have to do; the planner handles this.
  - Except: Make sure your database is getting VACUUMed properly!

Lossy Index Scans.

- Some index scans are “lossy”: It knows that some tuple in the page it is getting probably matches the query condition, but it’s not sure.
- This means that it has to retrieve pages and scan them again, throwing away rows that don’t match.
- Bitmap Index Scan / Bitmap Heap Scan are the most common type of this…
- … although some index types are inherently lossy.

Covering Indexes.

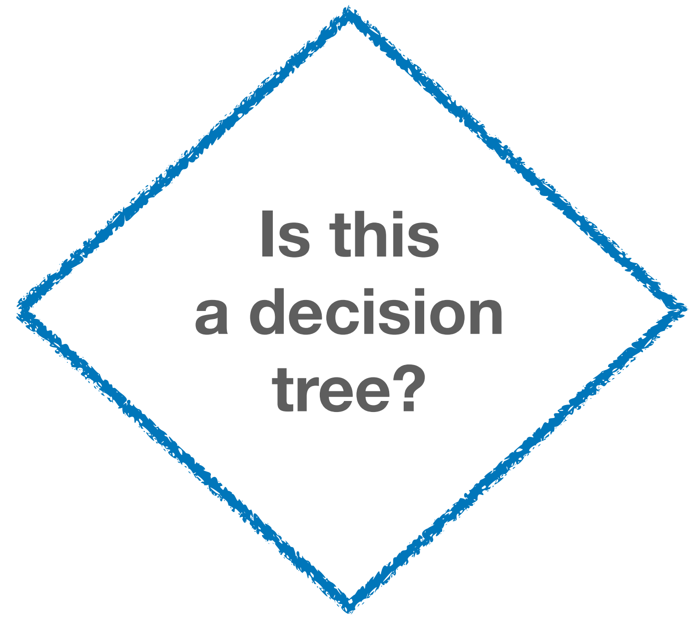
- Queries often return columns that aren't in the indexed predicates of the query.
- Traditionally, PostgreSQL had to fetch the tuple from the heap to get those values (after all, they aren't in the index!).
- Non-indexed columns can be added to the index… retrieved directly when the index is scanned.
    - Doesn't help on non-Index Only Scans, and remember: you are increasing the index size with each column you add.

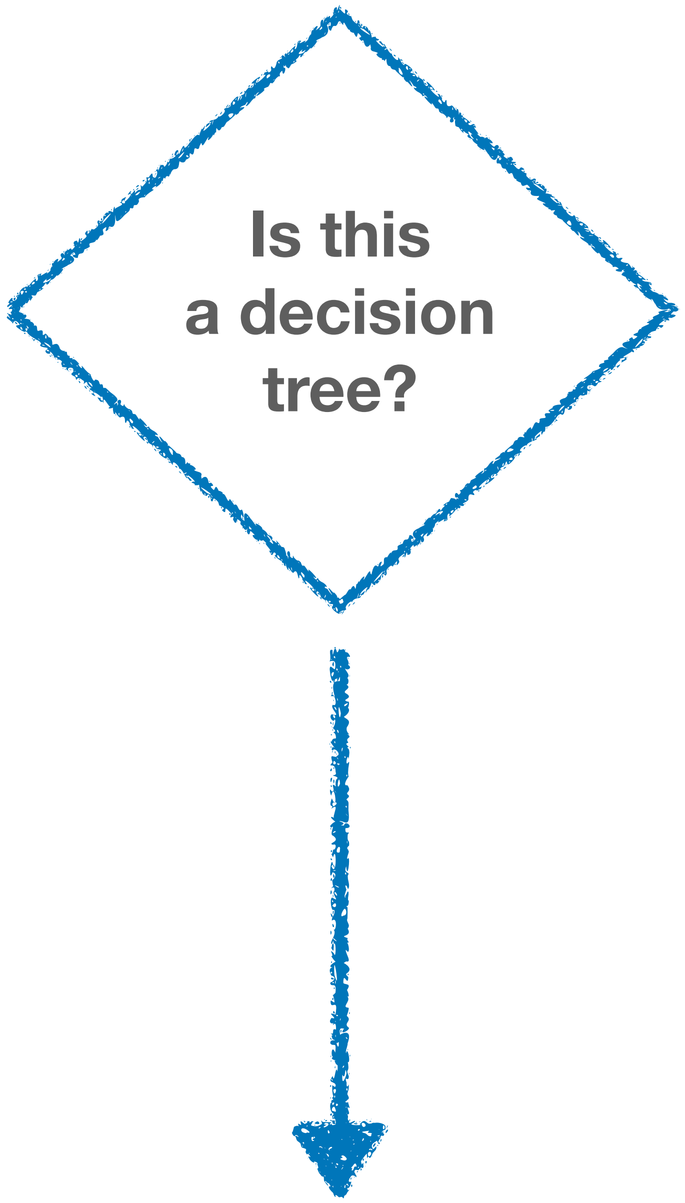
GIN Posting.

- GIN indexes are very fast to query, but much slower to update than other types of index.
- PostgreSQL records changes in a separate posting area, and updates the index at VACUUM time (or on demand).
- This can result in a surprising spike of activity on heavily-updated GIN indexes.
- Consider having a separate background process that calls `gin_clean_pending_list()`.

UNIQUE indexes.

- B-Trees support unique indexes.
- Optimistic insertion with recovery on index conflicts is a perfectly fine application development strategy.
  - ON CONFLICT … makes this much easier.
- This can be a concurrency-killer, so don’t expect very high insertion rates in the face of conflicts.
- Exclusion constraints provide a generalization of UNIQUE (“only one value that passes this comparison is allowed in this table”).


Is this
a decision
tree?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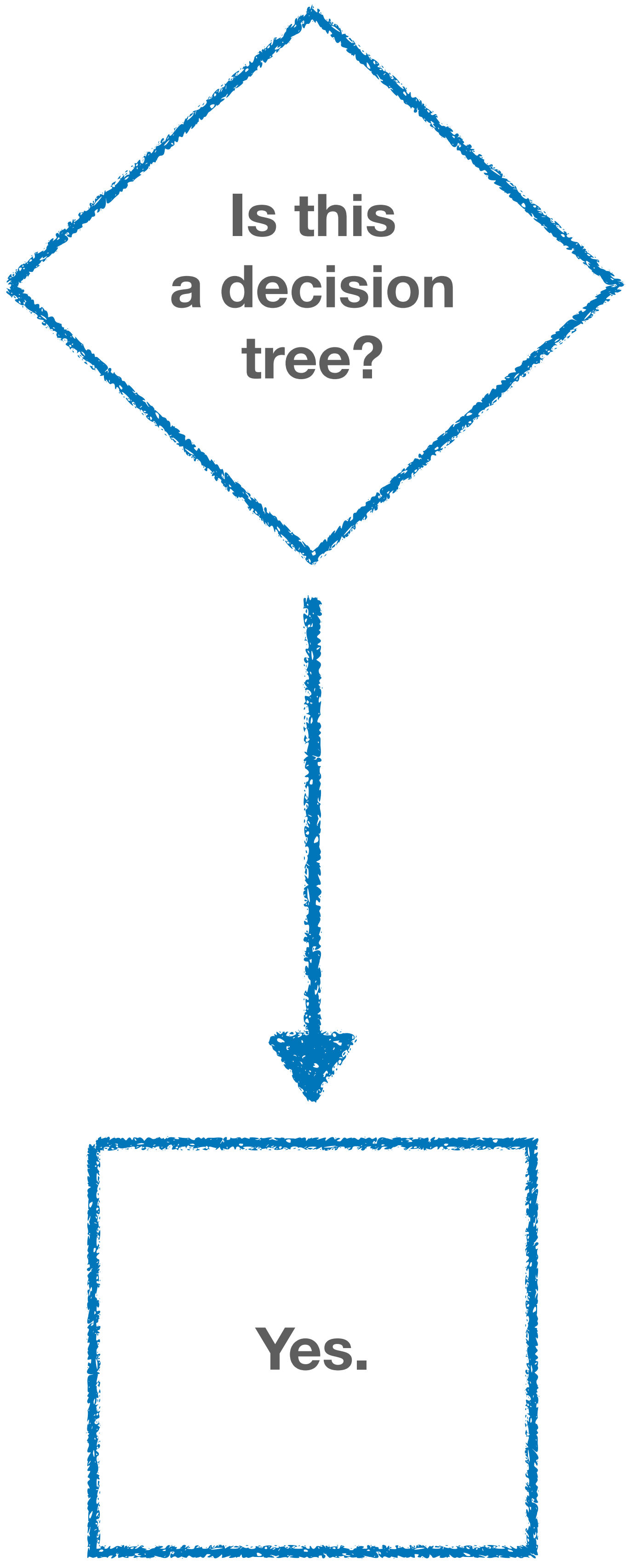
Is this
a decision
tree?
Yes.

What index?

- How do we decide what index to use in a particular situation?
- First, gather some information:
    - Typical queries on the table.
    - The columns, data types, and operators that are being queried.
        - Including those in JOINs.
    - How many rows the queries typically return.

How many rows?

- Does the query typically return a large percentage of the table?
  - Including “hidden” row fetches, such as COUNT(*).
- If so… an index probably won’t help!
- Refactor the query, consider summary tables or other techniques before just throwing an index at the problem.
- Small tables that fit in memory usually don’t need indexes at all, except to enforce constraints.

Which column?

- In a multi-predicate query, which column?
- Always start with the most selective predicate.
  - That is, the one that will cut down the number of rows being considered the most.
- If the predicates individually don't cut the results down much, but do so together, that's a good sign a multi-column index will be useful.
- But first, let's consider a single column.

Is the column a small scalar?

- int, bigint, float, UUID, datetime(tz)… (but see later for inet and char types).
  - UUIDs have special considerations in B-tree indexes.
- Is the value a primary key or otherwise UNIQUE?
  - If so, B-Tree.
- Is it monotonically increasing on a large, rarely updated table, and the query is doing a range operation?
  - If so, BRIN.
- Otherwise, B-Tree.
  - If the index is primarily to support ORDER BY … DESC, create as descending; otherwise, ascending.

Is the column a text field?

- varchar(), text, or char (if you’re weird).
- Are you doing full-text search, trigrams, or other fuzzy search techniques?
  - Trick question! See later.
- Is the data structured (and prefix-heavy) and you are typically doing prefix searches? (URLs are a typical case here.)
  - Consider SP-GiST.
- Is the value generally small (< 200 characters), or do you require total ordering?
  - If so, B-Tree.
- Otherwise, consider a Hash index.

Is the column a bytea?

- **Why** are you indexing a bytea?
- Don’t do this.
- **Please**.
- If you must, use Hash or calculate a hash and store it separately.

Is the column a range or geometric type?

- GiST is there for you.
- PostGIS indexes are all GiST-based.
- If you need nearest-neighbor searching, GiST for sure.
  - The “Starbucks problem.”
- Experiment with SP-GiST to see if it is a good fit for your data distribution.

Is the column type inet?

- Are you just doing equality?
  - B-Tree
  - (Try Hash to see if it works better for you.)
- Are you doing prefix searches?
  - Consider SP-GiST.

Is the column an array or JSONB?

- Are you just doing equality?
  - Hash.
- Are you searching for key values?
  - GIN.

Is the column JSON-no-B?

- Why is the column JSON?
- Expression index is the only option here.
- If you need indexing, far better to convert it to JSONB.

Are you doing full-text or fuzzy search?

- Full text search: Create a `tsvector` from the text, and create a GIN index on that.
    - Either store as a separate column, or use an expression index.
    - Separate columns are better for complex `tsvector` creation.
- Fuzzy search: Create an index on the column using `gist_trgm_ops` (part of the `pg_trgm` contrib package).

Is there more than one column in the predicate?

- Consider creating a multi-column index, if the predicates together are highly selective.
- Remember that in an index on (A, B), PostgreSQL will (almost!) never use it for just a search on B.
- Find the right index type for each column individually, and create the index based on the most selective column.
- If one column requires a GiST index, you can use the `btree_gist` package to get GiST operators for basic scalar types.

Is there more than one column in the predicate?

- If the query pattern is an arbitrary equality comparison of the various columns, consider a Bloom index.
  - Not uncommon with a GUI-driven search filter.
- If the predicates are selective independently, two indexes might be superior… test!

Does the query contain an expression?

- Consider creating an expression index.
- For example, an index on `unaccent(lower(name))` instead of querying on it.
  - Don't forget the citext type for the `lower()` problem, though.
- Be sure that particular expression is very heavily queried.
- If you index on a user-written function, make sure it really is IMMUTABLE, not just declared that way.

Is one predicate highly selective?

- `SELECT * FROM orders WHERE customer_id = 12 AND active;`
  - … where only 10% of orders are "active".
- Consider creating a partial index.
  - `CREATE INDEX ON orders(customer_id) WHERE active;`
- Only contains the rows that match the predicate.
- Can significantly speed up index queries.


Tools.

Do we need an index?

- `pg_stat_user_tables`.
- Look for tables with a significant number of sequential scans.
- Not all sequential scans are bad! Dig into the particular queries, look at their execute plans.
- `pg_stat_statements`, the text logs, and `pgbadger` are your friends here.

Will an index help?

- `https://github.com/HypoPG/hypopg`
- Allows creation of “hypothetical” indexes.
- Create index, EXPLAIN the query, see if it is being used.
- “Being used” and “makes the query faster” are not always the same thing.
- RDS, at least, supports it.

Is the index being used?

- `pg_stat_user_indexes`.
- Look for indexes that aren't being used.
- Drop indexes that aren't benefiting you.
- Indexes have a large intrinsic cost in disk space and UPDATE/INSERT time.
- https://github.com/pgexperts/pgx_scripts/blob/master/indexes/unused_indexes.sql

Are indexes bloated?

- Indexes can suffer from bloat.
- VACUUM can't always reclaim space efficiently, due to index structure.
- Periodic index rebuilds are worth considering.
- https://github.com/pgexperts/pgx_scripts/blob/master/bloat/index_bloat_check.sql

Are indexes corrupted?

- It doesn’t happen often, but it does happen.
- Errors during queries, etc.
- PostgreSQL 10+ has `amcheck`.
- Easy to fix! Drop and recreate the index.

To Conclude

Indexes are great.

- Remember that they are an optimization.
- Always create in response to particular query situations.
- Experiment! Test different index types to see what works best.
- Pick the right index type for the data… don’t just go with B-Tree by default.
- Monitor usage and size to keep the database healthy and trim.

Thank you!

Questions?

Christophe Pettus

CEO, PostgreSQL Experts, Inc.

christophe.pettus@pgexperts.com

twitter @xof

thebuild.com